TECHNICAL BULLETIN No. 253 JULY, 1940



# New York State Agricultural Experiment Station

Geneva, N. Y.

## FACTORS AFFECTING THE QUALITY OF LIMBURGER CHEESE MADE FROM PASTEURIZED MILK

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PUBLISHED BY THE STATION
UNDER AUTHORITY OF CORNELL UNIVERSITY

## ABSTRACT

WITH few exceptions, limburger cheese is manufactured in this country from raw milk. The use of pasteurized milk presents new problems to cheesemakers. Factors affecting the quality of limburger cheese made from milk heated to 145° F (62.8° C) have been studied.

Forty lots of limburger cheese comprising 172 1-pound cheeses were made at a limburger cheese factory by the manufacturing method commonly used with raw milk. Both partial and complete pasteurization of the milk markedly improved the quality of cheese made in July and August from poor quality milk but not that made in October from milk of better quality. Pasteurization of the milk at 145° F for 30 minutes resulted in as good cheese as partial pasteurization using holding periods of 0, 10, 15, and 20 minutes.

Limburger cheese made from pasteurized milk had a milder flavor than that made from raw milk. Flavor development in the pasteurized milk cheese varied with individual lots and was usually most pronounced when starter was not added to the milk. With some lots starter was not beneficial, while with others the addition of 0.05 or 0.10 per cent of lactic starter improved the grade of the cheese. Results obtained with starter hold true only for the one method of manufacture used in these studies. Experience by the industry indicates that special manufacturing methods may be desirable with pasteurized milk.

Pasteurization of milk for the manufacture of limburger cheese results in a product of uniformly good quality when the proper manufacturing method is followed.

Technical Bulletin No. 253

# FACTORS AFFECTING THE QUALITY OF LIMBURGER CHEESE MADE FROM PASTEURIZED MILK[1]

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## INTRODUCTION

APPROXIMATELY 10 million pounds of limburger cheese are made annually in this country, mostly in New York State and Wisconsin. This cheese is made principally from raw milk which varies in quality thruout the year, and as a result, the cheese is not uniform in quality. The development of gas in cheese made from raw milk is common during hot summer weather. This type of defect is readily controlled by pasteurization or heat treatment of the milk. In view of the above situation, why is pasteurization not generally used in the limburger cheese industry?

In addition to economic reasons, doubt exists in the minds of many cheesemakers and others associated with the industry in regard to the possibility of making a good commercial grade of limburger from pasteurized milk. Some of the questions which have been raised in this connection follow.

Will cheese made from pasteurized milk develop a typical limburger flavor? Is complete or partial pasteurization most favorable for the quality of the product? How does the grade of limburger cheese made from raw and from pasteurized milk of good quality compare with that made from raw and from pasteurized milk of poor quality? Is starter necessary and, if so, what is the optimum amount to be added to pasteurized milk? Will limburger cheese made from pasteurized milk be accepted by the trade?

Present studies have been limited to the method ordinarily used in New York State for making limburger cheese from raw milk.

## HISTORICAL

While pasteurization of milk for cheddar cheese has received much study, very little has been done in the case of limburger. Zeiler and

[1]Acknowledgment should be made to the Miller-Richardson Company and to the Kraft Cheese Company for facilities and materials supplied in the field, also for helpful suggestions and assistance in grading the cheese. This investigation was made possible by the Federal Bankhead-Jones Fund.

Berwig (12)[2] in 1930 in Germany found that pasteurization at 145° F (62.8° C) for 10 to 20 minutes controlled gas and usually resulted in a better cheese of the limburger type than the customary holding of 30 minutes. Claussen (2) in 1938 studied milk pasteurized for a short time at 160° to 165° F (71.1° to 73.9° C). Cheeses made from pasteurized milk without starter were defective, whereas cheeses made from pasteurized milk to which 0.5 per cent starter was added were on the whole somewhat better than those made from raw milk. Cultures successfully used were strong acid-producing strains of *Streptococcus lactis* and *Streptococcus cremoris*. Cultures of *Lactobacillus casei* and *Lactobacillus helveticus* were unsuited.

Kelly (5) in 1939 found that cheeses made from milk held for 5 and 10 minutes at 145° F (62.8° C) showed some gas, while those made from milk held for 15 and 20 minutes were entirely free of gas and of satisfactory quality. When milk was flashed to 163° F (72.8° C), the cheeses were free from gas and of excellent quality and flavor. However, when the milk was heated to 160° F (71.1° C) and 162° F (72.2° C) with a holding time of 15 seconds, raw milk cheeses in two trials were superior to those made from pasteurized milk. Kelly recognized the need for further studies of suitable methods for manufacturing pasteurized milk into limburger cheese.

Kara-Oglanow (4) in 1939 in Russia studied the effect of storage temperatures as well as pasteurization. The limburger cheese with the best flavor was manufactured from pasteurized milk and was stored at temperatures of 32° to 37° F (0° to 3° C), likewise 41° to 45° F (5° to 7° C) rather than 50° to 54° F (10° to 12° C). Cheese packed in tin foil had a better flavor and texture than that packed without tin foil except in the case of cheese stored at the higher temperatures, when the reverse occurred.

A number of companies in this country have successfully manufactured soft cheeses of the Trappist type from pasteurized milk and have found that pasteurization improved the quality of the product. Marquardt (7) described the manufacture of cheeses of this type which characteristically have a mild limburger flavor and ripen in somewhat the same manner as limburger.

A few limburger cheese factories control gas during the summer by heating the milk in the vat to about 145° F. This cannot rightly be termed pasteurization since the milk is cooled immediately to the setting temperature. About 0.10 per cent starter is usually added to the milk. Limburger cheese made under these conditions is milder in flavor and cures more slowly than cheese made from raw milk.

The Kraft Cheese Company in 1939, following studies in the Stockton, Illinois, laboratories by Pulkrabek and associates, began the manufacture of limburger cheese from pasteurized milk (145° F for 30 minutes) at a factory near Monroe, Wisconsin.[3] The method

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[2]Figures in parenthesis refer to Literature Cited, page 28.

[3]*Cheese Reporter*, 64 (8). 1939.

commonly used with raw milk resulted in a cheese that was short in body. Special manufacturing methods were developed which prevented this defect and yielded a cheese with a body somewhat softer and more buttery and plastic than that of raw milk cheese. While flavor develops more slowly in this cheese than in limburger cheese made from raw milk, it is great enough to satisfy the majority of consumers when two months old.

## METHODS

### PASTEURIZATION

Two 10-gallon cans were filled with raw milk from the cheese vat. After removing 42.5 pounds for the control lot of cheese, the remaining 127.5 pounds were partly or completely pasteurized by placing the cans in hot water at 160° F (71.1° C) and stirring the milk until the temperature reached 143° F (61.7° C). The water temperature was then adjusted to 147° F (63.9° C) and the milk held the required time at about 145° F (62.8° C). Pre-heating and cooling each required from 20 to 25 minutes.

### EXPERIMENTAL CHEESE VATS

Stainless steel vats 18 inches long, 9 inches wide, and 12 inches deep (inside dimensions) were used. These dimensions permitted cutting the curd uniformly with 8-inch curd knives. Outlets were not provided, the curd being dipped from the vats with a strainer dipper. Each vat had wooden supports, 2 inches high and 9 inches long, fastened beneath the vat at the ends which permitted the heating water to circulate under the vat. The four experimental vats were held in a large vat containing water as the heating medium and were placed so that each experimental vat was heated from the four sides and from the bottom.

### MANUFACTURING PROCEDURE

Starter was prepared from a commercial lactic culture of the type ordinarily supplied to cheesemakers.[4] It was carried at 68° F (20.0° C). The 18-hour-old starter at time of use had a titratable acidity of 0.70 to 0.80 per cent expressed as lactic acid.

The manufacturing procedure was similar to that ordinarily used in New York State factories for raw milk cheese.

The milk was set at 86° to 88° F (30.0° to 31.1° C) with 1 cc of rennet per 10 pounds of milk. The best possible cheese was made from each lot of milk. About 15 minutes after cutting, heat was applied and the curd heated gradually to about 96° F (35.6° C) and held at this temperature until ready to dip. The curd was then transferred to wooden forms with a strainer dipper, and the forms turned frequently during the first six hours.

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[4]Furnished thru courtesy of Chr. Hansen's Laboratory, Inc.

As soon as the curd was sufficiently firm, each lot was cut into four cheese (five in series 10–12), dimensions 5 inches x 2½ inches x 2–3 inches, which weighed about 1 pound when ready for market. After cutting, the cheese were salted by rubbing and packed closely together until the following morning when they were again salted by rubbing and piled two deep. About 24 hours after the second salting, the cheese were placed on the shelves where they were turned and rubbed at intervals by the cheesemaker. At 9 to 15 days of age, they were wrapped in parchment, wax paper, and foil and placed in cold storage at about 50° F (10.0° C).

### ANALYTICAL PROCEDURE

The cheeses were sampled by cutting a cross section slice approximately 2½ inches x 2½ inches x ¼ inch which was taken at least 1 inch away from an end or previously cut surface. In the sample used for moisture and salt determinations, the rind was discarded to a depth of ⅛ inch, but in the sample used for hydrogen-ion determinations the rind and adhering slime were included. Kelly and Marquardt (6) have shown that in the ripening of limburger greatest changes in pH values occur at and next to the surface. If the rind was firm and dry, it was ground separately in a mortar, the remainder of the sample added, and the mixture ground until homogeneous. Hydrogen-ion determinations were made with a quinhydrone electrode using the straight gold-plated platinum wire electrode described by Sanders and Whittier (10). A large size paper drinking straw (¼ inch outside diameter) approximately 1½ inches long was used to hold the cheese-quinhydrone mixture.

Moisture and salt determinations were carried out on 3-gram samples according to the methods outlined by Wilster, *et al.* (11) for hard cheese.[5] Marquardt (8) showed that the salt method recommended for hard cheese gave reliable results with limburger cheese. Moisture determinations were made in duplicate and salt determinations singly when the cheese were three to four weeks old.

## RESULTS

The experimental cheese were made at a limburger cheese factory in New York State by the method ordinarily used for raw milk. Forty lots, comprising 172 cheeses, were made in 10 series of experiments using 0, 10-, 15-, 20-, and 30-minute holding periods at 145° F (62.8° C) and amounts of starter ranging between 0.0 and 0.2 per cent. In each series, a control lot of cheese (A) was made from raw milk without starter, the usual manufacturing procedure in New York State factories. A total of 1,700 pounds of milk was used in the ex-

[5]Since this work was completed, methods for the analyses of soft cheese have been published in the *Journal of Dairy Science* (Vol. 23, page 197).

periments, each lot of cheese being made from 42.5 pounds of milk. Series 1 and 2 represent preliminary work and for this reason are not included in this report.

### QUALITY OF MILK

In July, about 3,000 pounds of milk testing approximately 3.2 per cent fat and in October about 1,600 pounds of milk testing approximately 4.0 per cent fat were received daily from 14 patrons. In each series of experiments, 170 pounds of raw milk were used from the composite supply in the cheese vat.

Between July 26 and August 9, atmospheric temperatures were high and the milk had a high direct microscopic count. The count of clumps ranged between 900,000 and 7,500,000 per ml. and the count of individual bacteria between 3,600,000 and 90,000,000 per ml. (Table 1). Since gas-forming bacteria of the coliform group are particularly objectionable in limburger cheese, the number of coliform organisms was roughly determined by using single tubes of formate-ricinoleate broth per decimal dilution. The July-August milk contained about 100,000 coliform organisms per ml.

In October the bacterial quality of the milk was much improved due to lower atmospheric temperatures, clump counts ranging between 100,000 and 600,000 per ml. and individual bacteria counts between 400,000 and 6,000,000 per ml. Coliform organisms were far fewer in number, being about 1,000 per ml. in the October milk.

Titratable acidities expressed as lactic acid ranged from 0.15 to 0.16 per cent, the October milk having practically the same acidity as the July and August milk. Whey at time of dipping titrated 0.100 to 0.105 per cent expressed as lactic acid.

### EFFECT OF TREATMENT OF MILK ON MANUFACTURING PROCEDURE

Cutting of the curd took place 30 to 57 minutes after setting. The time from setting to dipping ranged from 1 hour and 24 minutes to 3 hours and 33 minutes (Table 2). Curd from raw milk without starter was dipped in about 1½ to 2 hours from time of setting, while curd made from pasteurized milk without starter firmed more slowly and in some instances was not ready to dip until about 3½ hours after setting. The longer time required in the latter case was due to retardation of acid development as a result of the destruction of lactic acid-forming bacteria by pasteurization. Addition of starter to the pasteurized milk hastened acid development. With 0.2 per cent starter,

Table 1.—Quality of Raw Milk Used in Manufacture of Control Lots of Experimental Limburger.

| Series | Date, 1939 | Direct microscopic count | | Coliform test* dilution | | | | Titratable acidity |
|---|---|---|---|---|---|---|---|---|
| | | Clumps | Individuals | 1/1,000 | 1/10,000 | 1/100,000 | 1/1,000,000 | |
| 3 | July 26 | | | | Not examined | | | 0.150 |
| 4 | July 27 | 900,000 | 3,600,000 | + | + | + | − | 0.150 |
| 5 | Aug. 1 | 7,500,000 | 45,000,000 | + | + | + | − | 0.160 |
| 6 | Aug. 2 | 4,500,000 | 90,000,000 | + | + | + | − | 0.160 |
| 7 | Aug. 3 | 4,500,000 | 36,000,000 | + | + | − | − | 0.150 |
| 8 | Aug. 8 | 4,500,000 | 13,500,000 | + | + | + | − | 0.160 |
| 9 | Aug. 9 | 1,500,000 | 22,500,000 | | Not examined | | | —— |
| 10 | Oct. 24 | 150,000 | 500,000 | + | − | − | − | 0.155 |
| 11 | Oct. 25 | 100,000 | 400,000 | | Not examined | | | —— |
| 12 | Oct. 26 | 600,000 | 6,000,000 | + | − | − | − | 0.150 |

*Formate-ricinoleate broth, one tube per dilution. +Gas produced. −No gas produced.

TABLE 2.—EFFECT OF HEAT TREATMENT OF MILK AND ADDITION OF STARTER ON TIME OF DIPPING, SALTING AND MOISTURE CONTENT OF EXPERIMENTAL LIMBURGER.

| Lot | Treatment of milk | | Manufacturing time | | | Composition | |
|---|---|---|---|---|---|---|---|
| | Minutes at 145°F | Per cent starter | Setting to dipping, minutes | Dipping to first salting, hours | First to second salting, hours | Moisture, per cent | Salt, per cent |
| | | | I. July and August | | | | |
| 3A | Raw | 0.00 | 117 | 18 | 24 | 38.1 | 2.03 |
| 3B | 30 | 0.00 | 210 | 18 | 24 | 42.4 | 2.40 |
| 3C | 30 | 0.10 | 148 | 18 | 24 | 40.3 | 2.00 |
| 3D | 30 | 0.20 | 131 | 18 | 24 | 38.2 | 1.93 |
| 4A | Raw | 0.00 | 115 | 6 | 12 | 40.6 | 2.46 |
| 4B | 30 | 0.00 | 213 | 18 | 24 | 44.1 | 2.23 |
| 4C | 30 | 0.10 | 157 | 18 | 24 | 39.8 | 2.10 |
| 4D | 30 | 0.20 | 130 | 18 | 24 | 38.5 | 2.06 |
| 5A | Raw | 0.00 | 101 | 6 | 12 | 40.7 | 2.26 |
| 5B | Raw | 0.05 | 102 | 6 | 12 | 40.3 | 2.30 |
| 5C | Raw | 0.10 | 110 | 6 | 12 | 39.7 | 2.33 |
| 5D | Raw | 0.20 | 118 | 6 | 12 | 38.3 | 2.47 |
| 6A | Raw | 0.00 | 117 | 6 | 14 | 40.5 | 2.47 |
| 6B | 0 | 0.00 | 177 | 18 | 24 | 41.7 | 2.55 |
| 6C | 15 | 0.00 | 185 | 18 | 24 | 42.3 | 2.76 |
| 6D | 30 | 0.00 | 193 | 18 | 24 | 40.5 | 2.76 |
| 7A | Raw | 0.00 | 94 | 7 | 24 | 37.8 | 2.40 |
| 7B | 0 | 0.05 | 120 | 6 | 24 | 39.0 | 2.06 |
| 7C | 0 | 0.10 | 123 | 6 | 24 | 38.9 | 2.23 |
| 7D | 0 | 0.20 | 126 | 6 | 24 | 38.2 | 2.46 |
| 8A | Raw | 0.00 | 95 | 7 | 14 | 38.3 | 2.13 |
| 8B | 10 | 0.05 | 133 | 6 | 14 | 42.8 | 2.00 |
| 8C | 10 | 0.10 | 121 | 6 | 14 | 40.5 | 2.03 |
| 8D | 10 | 0.20 | 110 | 6 | 14 | 41.5 | 2.10 |
| 9A | Raw | 0.00 | 109 | 7 | 12 | 41.8 | 2.66 |
| 9B | 20 | 0.05 | 135 | 6 | 12 | 41.4 | 2.26 |
| 9C | 20 | 0.10 | 123 | 6 | 12 | 41.8 | 2.09 |
| 9D | 20 | 0.20 | 110 | 6 | 12 | 41.3 | 2.16 |
| | | | II. October | | | | |
| 10A | Raw | 0.00 | 132 | 20 | 24 | 48.7 | 2.37 |
| 10B | 10 | 0.00 | 141 | 20 | 24 | 51.5 | 2.43 |
| 10C | 10 | 0.10 | 150 | 20 | 24 | 48.9 | 2.37 |
| 10D | 10 | 0.20 | 158 | 20 | 24 | 48.2 | 2.57 |
| 11A | Raw | 0.00 | 85 | 20 | 24 | 49.2 | 2.30 |
| 11B | 20 | 0.00 | 108 | 20 | 24 | 49.7 | 2.40 |
| 11C | 20 | 0.10 | 96 | 20 | 24 | 46.2 | 2.17 |
| 11D | 20 | 0.20 | 84 | 20 | 24 | 45.7 | 2.17 |
| 12A | Raw | 0.00 | 105 | 20 | 24 | 46.3 | 2.43 |
| 12B | 30 | 0.00 | 118 | 20 | 24 | 46.5 | 2.67 |
| 12C | 30 | 0.10 | 111 | 20 | 24 | 44.1 | 2.77 |
| 12D | 30 | 0.20 | 104 | 20 | 24 | 42.7 | 2.47 |

Table 3.—Average Grade of Limburger Cheese Manufactured in July and August.*

| Series and lot | Treatment of milk | | Body and texture of cheese | | | | Flavor of cheese | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Minutes at 145°F | Per cent starter | Av. grade | | Comments on quality | | Av. grade | | Comments on quality | |
| | | | 7 weeks | 12 weeks | 7 weeks | 12 weeks | 7 weeks | 12 weeks | 7 weeks | 12 weeks |
| 3A | Raw | 0.00 | 2.9 | 3.0 | Open, firm, dry | Open, firm, dry | 2.8 | 3.8 | Sharp | Strong, off |
| 3B | 30 | 0.00 | 1.9 | 1.6 | | | 2.7 | 2.4 | Lacking flavor | Mild, lacking flavor |
| 3C | 30 | 0.10 | 2.8 | 2.6 | Firm | Firm, brick-like | 3.2 | 3.0 | Lacking flavor | Mild, lacking flavor |
| 3D | 30 | 0.20 | 2.9 | 2.8 | Firm | Firm, dry, brick-like | 3.4 | 3.4 | Lacking flavor | Mild, lacking flavor |
| 4A | Raw | 0.00 | 3.3 | 3.6 | Open, firm, dry | Firm, crumbly | 3.2 | 4.4 | Sharp | Bitter |
| 4B | 30 | 0.00 | 3.1 | 3.2 | Acid core, dry | | 3.3 | 3.2 | Acid | Mild, off |
| 4C | 30 | 0.10 | 2.9 | 2.9 | Acid core | Dry | 3.0 | 3.2 | Lacking flavor | Lacking flavor, mild |
| 4D | 30 | 0.20 | 3.0 | 2.8 | Acid core | Dry | 3.0 | 3.0 | Lacking flavor | Mild |
| 5A | Raw | 0.00 | 3.0 | 3.3 | Open, firm, dry | Open, brittle center | 2.8 | 4.6 | Sharp, acid | Bitter |
| 5B | Raw | 0.05 | 3.3 | 3.2 | Open, firm, dry | Firm, dry | 3.0 | 3.9 | Sharp, acid | Off |
| 5C | Raw | 0.10 | 3.2 | 3.7 | Open, firm, dry | Acid, dry, brittle | 3.0 | 3.5 | Sharp, acid | Sharp |
| 5D | Raw | 0.20 | 3.2 | 3.8 | Open, firm, dry | Acid, dry, brittle | 3.1 | 3.4 | Sharp, acid | Sharp |
| 6A | Raw | 0.00 | 3.2 | 3.3 | Open, firm, dry | | 2.9 | 3.5 | Sharp, acid | Sharp |
| 6B | 0 | 0.00 | 2.6 | 3.9 | Dry | Discolored | 3.0 | 4.5 | Sharp, lacking flavor | Off |
| 6C | 15 | 0.00 | 2.4 | 3.2 | Dry | | 2.8 | 3.4 | Flat, lacking flavor | |
| 6D | 30 | 0.00 | 3.2 | 3.6 | Dry, corky | | 3.2 | 3.4 | Sharp, lacking flavor | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 7A | Raw | 0.00 | 3.1 | 3.4 | Firm, dry | Dry, brittle | 3.0 | 3.3 | Sharp | |
| 7B | 0 | 0.05 | 2.2 | 1.8 | Dry | | 2.9 | 2.3 | Lacking flavor | |
| 7C | 0 | 0.10 | 2.6 | 2.3 | Firm, dry | Dry | 2.4 | 3.0 | Lacking flavor | Lacking flavor, mild |
| 7D | 0 | 0.20 | 2.9 | 2.6 | Firm, dry | Dry | 2.9 | 3.1 | Lacking flavor | Lacking flavor, mild |
| 8A | Raw | 0.00 | 3.3 | 3.6 | Open, dry | Open | 4.1 | 4.4 | Sharp, unclean | Off |
| 8B | 10 | 0.05 | 2.1 | 2.0 | | | 2.4 | 2.9 | | Lacking flavor, mild |
| 8C | 10 | 0.10 | 2.3 | 1.8 | Dry | | 2.4 | 2.5 | Lacking flavor | Lacking flavor, mild |
| 8D | 10 | 0.20 | 2.3 | 2.5 | | Dry | 2.4 | 2.9 | Lacking flavor | Lacking flavor, mild |
| 9A | Raw | 0.00 | 4.6 | 4.6 | Very open | Very open | 5.0 | 5.0 | Bitter, unclean | Bitter, unclean |
| 9B | 20 | 0.05 | 2.8 | 1.6 | Curdy, firm | | 2.8 | 2.3 | Lacking flavor | |
| 9C | 20 | 0.10 | 2.5 | 1.6 | | | 2.6 | 2.3 | Lacking flavor | |
| 9D | 20 | 0.20 | 2.5 | 2.0 | | | 2.8 | 2.7 | Lacking flavor | |

*Key to grades: 1 = Excellent; 2 = Desirable; 3 = Satisfactory; 4 = Objectionable; 5 = Very Objectionable; 6 = Unsalable.

the curd from pasteurized milk was ready to dip as soon or nearly as soon as was the curd from raw milk. With lesser amounts of starter, acid development was slower and the curd consequently not ready to dip as soon.

During July and August, atmospheric temperatures in the factory were as high at 86° F (30.0° C). This hastened acid development in the curd following dipping and facilitated drainage so that the curd in the forms was usually ready to cut into individual cheeses and to salt about 6 hours after dipping. In October, atmospheric temperatures in the factory were much lower, ranging from 50° F (10.0° C) to 70° F (21.1° C). Compared with summer conditions, the curd cooled more rapidly following dipping, drained more slowly and it was necessary to leave it overnight in the forms in the "make room" before cutting into individual cheese and salting.

The July and August cheeses held in the cellar at 70° F (21.1° C) developed more rapidly than the October cheeses held at 60° F (15.6° C) and were ready to wrap several days earlier.

Moisture analyses were made upon the partly cured cheeses at three to four weeks of age. The moisture content of the July-August cheeses ranged from 37.8 to 44.1 per cent and that of the October cheeses from 42.7 to 51.5 per cent (Table 2). These moisture percentages are within the range reported in the literature for commercial limburger. Salt contents of all experimental lots ranged from 1.93 to 2.77 per cent (Table 2). Based on dry matter, fat contents ranged from 54 to 58 per cent.

## QUALITY OF EXPERIMENTAL CHEESES

The quality of the July and August cheeses (series 3 to 9) was determined by five judges (Table 3). Grading was done according to a scheme used by Byers and Price (1) in which a grade of 1 was considered excellent, 2 desirable, 3 satisfactory, 4 objectionable, 5 very objectionable, and 6 unsalable. The judges, except for the author, were men in the industry who were familiar with the qualities desired in commercial limburger.

All of the raw milk cheeses (lots 3A, 4A, 5A-B-C-D, 6A, 7A, 8A, and 9A) were appreciably gassy. Lots 8A and 9A were very gassy. Corresponding lots of cheeses made from partly or completely pasteurized milk contained few or no gas holes, the majority of the holes and openings being mechanical in nature (Fig. 1).

At seven weeks of age, body and texture grades of the raw milk

cheeses ranged from 2.9 to 4.6 and of cheeses made from partly or completely pasteurized milk from 1.9 to 3.2 (Table 3). Flavor grades ranged from 2.8 to 5.0 for raw milk cheeses and from 2.4 to 3.4 for pasteurized milk cheeses.

At the time of this first scoring, little difference was found between the quality of control cheeses (A) made from raw milk and those made from partly and completely pasteurized milk except in series 8 and 9 where raw milk cheeses were decidedly inferior. Lots 8A and 9A had objectionable body and texture (grades 3.3 and 4.6, respectively), and sharp, bitter unclean flavors (grades 4.1 and 5.0, respectively).

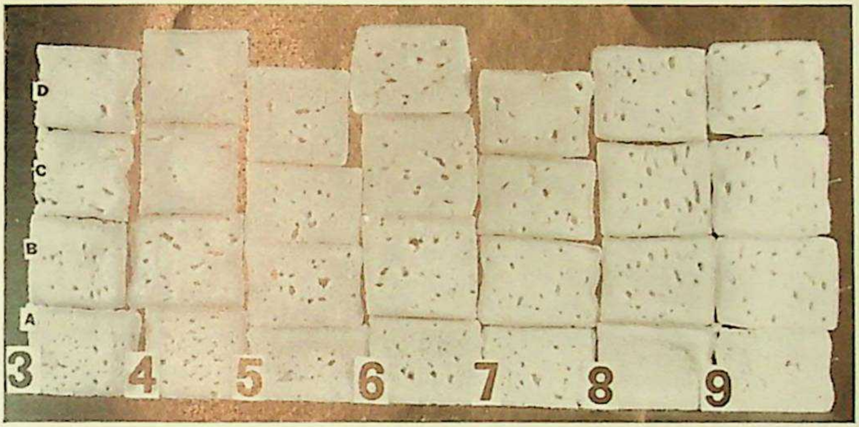


FIG. 1.—EXPERIMENTAL LIMBURGER CHEESE MADE IN JULY AND AUGUST. Cheese in bottom row and in third pile from left made from raw milk and remainder from milk pasteurized at 145° F for 0, 10, 20, or 30 minutes.

At 12 weeks of age, body and texture grades of raw milk cheeses ranged from 3.0 to 4.6 and of cheeses made from pasteurized milk from 1.6 to 3.9. Flavor grades ranged from 3.3 to 5.0 for raw milk cheeses and from 2.3 to 4.5 for pasteurized milk cheeses. The raw milk cheeses, with the exception of series 6, were decidedly inferior both in body and texture and in flavor to cheeses made from heated milk. The quality of the raw milk cheeses deteriorated between 7 and 12 weeks of age, indicated by lower grades at 12 weeks than at 7 weeks both for body and texture and for flavor, whereas the cheeses made from partly or completely pasteurized milk in many instances improved in quality during this period as evidenced by an improvement in grades. This is an important point to consider where limburger cheese is stored for some time.

All of the July and August cheeses were too firm and dry, an opinion confirmed by moisture analyses which ranged from 37.8 to 44.1 per cent (Table 2). The apparent softness of some of the cheeses in Fig. 1 was due in part to the age of the cheese at the time the photograph was taken (about eight weeks) and in part to pressure from upper layers of cheese.

Cheeses made from either partly or completely pasteurized milk were mild, lacking the full degree of limburger flavor characteristic of good raw milk cheese. The mild flavor was clean and pleasing in most instances and preferable to the sharp bitter flavor of the cheeses made from raw milk containing large numbers of gas-forming bacteria of the coliform group.

The quality of the October cheeses (series 10 to 12) was determined by four of the five judges who graded the July-August cheeses. Grading was done at 5 and 9 weeks of age (Table 4). At 5 weeks the cheeses were only partly cured. At 9 weeks the cheeses were well cured and at their prime. All October cheeses were of good quality, grades ranging from 1.5 to 3.4 for body and texture and from 1.9 to 3.0 for flavor. They contained few or no gas holes. Holes were mostly mechanical in nature (Fig. 2).

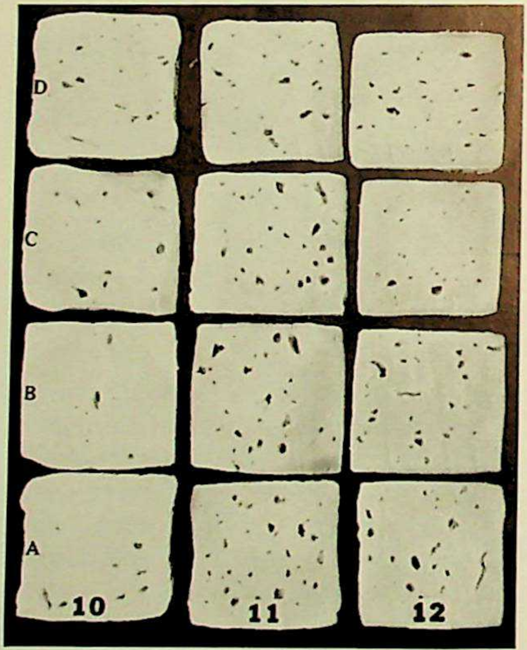


FIG. 2.—EXPERIMENTAL LIMBURGER CHEESE MADE IN OCTOBER FROM MILK OF BETTER QUALITY THAN THAT USED IN JULY AND AUGUST.

Cheese in bottom row made from raw milk and remainder from milk partly or wholly pasteurized.

## INFLUENCE OF STARTER ON CHEESE QUALITY

The best cheese in series 3, lot 3B, was made from pasteurized milk without starter. However, in series 4, there was no significant difference in the grade of cheese

TABLE 4.—AVERAGE GRADE OF LIMBURGER CHEESE MANUFACTURED IN OCTOBER.*

| SERIES AND LOT | TREATMENT OF MILK | | BODY AND TEXTURE OF CHEESE | | | | FLAVOR OF CHEESE | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Minutes at 145°F | Per cent starter | Av. grade | | Comments on quality | | Av. grade | | Comments on quality | |
| | | | 5 weeks | 9 weeks | 5 weeks | 9 weeks | 5 weeks | 9 weeks | 5 weeks | 9 weeks |
| 10A | Raw | 0.0 | 2.8 | 2.5 | Soft | Soft | 2.3 | 2.0 | | |
| 10B | 10 | 0.0 | 3.0 | 3.3 | Soft | Soft | 3.0 | 2.6 | Mild, sweet | Mild, lacking flavor |
| 10C | 10 | 0.1 | 1.5 | 2.8 | Soft | Soft | 2.3 | 2.5 | Mild, lacking flavor | Mild, lacking flavor |
| 10D | 10 | 0.2 | 2.5 | 2.1 | Soft | —— | 2.9 | 2.5 | Mild, lacking flavor | Mild, lacking flavor |
| 11A | Raw | 0.0 | 3.0 | 3.0 | Soft | Soft | 2.3 | 3.0 | | Slightly bitter |
| 11B | 20 | 0.0 | 3.0 | 3.4 | Soft | Soft | 3.1 | 3.0 | Acid | Slightly bitter |
| 11C | 20 | 0.1 | 2.3 | 2.6 | | | 2.5 | 2.4 | Mild, lacking flavor | Mild, lacking flavor |
| 11D | 20 | 0.2 | 2.4 | 2.4 | | | 2.8 | 2.3 | Mild, lacking flavor | Mild, lacking flavor |
| 12A | Raw | 0.0 | 2.0 | 1.8 | | | 2.3 | 2.1 | | |
| 12B | 30 | 0.0 | 2.8 | 1.5 | Soft | | 2.8 | 1.9 | Slightly acid | |
| 12C | 30 | 0.1 | 2.0 | 3.0 | | Acid core, firm | 2.5 | 2.8 | Mild, lacking flavor | Mild, lacking flavor |
| 12D | 30 | 0.2 | 2.0 | 2.6 | | Acid core, firm | 2.6 | 2.6 | Mild, lacking flavor | Mild, lacking flavor |

*Key to grades: 1 = Excellent; 2 = Desirable; 3 = Satisfactory; 4 = Objectionable; 5 = Very Objectionable; 6 = Unsalable.

made from pasteurized milk without starter and that made with 0.1 or 0.2 per cent of starter. In series 7, 8, and 9, concentrations of 0.05, 0.10, and 0.20 per cent starter were added to partly pasteurized milk. Under these conditions, the optimum amount of starter was 0.05 or 0.10 per cent. The addition of 0.20 per cent starter resulted in too dry a cheese which resembled brick cheese in body, texture, and flavor. In series 7, 8, and 9 the possibility of making good quality cheese without the addition of a small amount of starter was deemed improbable at the time and unfortunately was not tried.

Limburger cheese makers occasionally try to control gas in raw milk cheese by using a small amount of starter. The value of this procedure was studied in series 5. Varying amounts of starter (0.00, 0.05, 0.10, and 0.20 per cent) were added to raw milk containing large numbers of gas-forming bacteria. No appreciable difference in grades was observed at 7 weeks, but at 12 weeks cheese made from raw milk containing starter (except lot 5B) had poorer body and texture grades but better flavor grades than the corresponding cheese made from raw milk without starter. The increased acid development which took place as a result of using starter had a tendency to dry out the cheese as indicated by the correlation between the amount of starter, 0.00, 0.05, 0.10, and 0.20 per cent, and the amount of moisture, 40.7, 40.3, 39.7, and 38.3 per cent, respectively.

In October the addition of 0.00, 0.10, and 0.20 per cent starter to milk held for 10, 20, and 30 minutes at 145° F was studied. The moisture content of the cheeses ranged from 42.7 per cent for lot 12D to 51.5 per cent for lot 10B. All of the cheeses in series 10 were high in moisture, lots 10A, 10B, 10C, and 10D having moisture contents of 48.7, 51.5, 48.9, and 48.2 per cent, respectively. At 9 weeks, lot 10D with 0.2 per cent starter had the best body and texture in series 10, the average grade being 2.1 as compared to a grade of 2.5 for lot 10A, the raw milk control. However, the flavor grade of 2.5 for lot 10D compared to the grade of 2.0 for lot 10A shows that the former was somewhat inferior in flavor to the raw milk cheese.

In series 11, the milk was held for 20 minutes at 145° F. At 9 weeks, lot 11D with 0.2 per cent starter had the best grade for body and texture (2.4) and for flavor (2.3), followed closely by lot 11C with grades of 2.6 for body and texture and 2.4 for flavor. Lots 11A and 11B were high in moisture, 49.2 and 49.7 per cent, respectively, and for some unknown reason developed a slight bitter flavor. Lots

11C and 11D had a more desirable moisture content, 46.2 and 45.7 per cent, respectively.

In series 12, the milk was held for 30 minutes at 145° F. The importance of the proper moisture content is again brought out since lots 12A and 12B which were better than lots 12C and 12D and which graded 1.8 and 1.5, respectively, on body and 2.1 and 1.9, respectively, on flavor at 9 weeks, had respective moisture contents of 46.3 and 46.5 per cent. These two lots were the best of the October cheeses. Lot 12B made from pasteurized milk without the addition of starter had a slightly superior body and texture to lot 12A made from raw milk, the grades being 1.5 and 1.8, respectively. There was very little choice in flavor between 12B and 12A, grades being 1.9 and 2.1, respectively. The raw milk cheese, lot 12A, had a more pronounced limburger flavor than the pasteurized milk cheese, lot 12B, which had a mild but pleasing limburger flavor. Lots 12C and 12D were lacking in flavor. Undoubtedly, some consumers would prefer limburger cheese of a type similar to lot 12A and others a type similar to lot 12B.

### OPTIMUM HOLDING TIME AT 145° F

Momentarily heating the milk to 145° F without holding was sufficient to control gas. In this connection, it should be mentioned that a few gas holes are not objected to by the trade.

Cheeses which graded from desirable to satisfactory (2 to 3) were made regardless of whether the holding time for the milk was 0, 10, 20, or 30 minutes at 145° F. Examples are lots 7B, 8C, 9B, and 3B. The best of the October cheeses, lot 12B, was made from milk pasteurized for 30 minutes at 145° F.

### RELATION BETWEEN QUALITY OF MILK AND QUALITY OF CHEESE

In series 9, the raw milk was extremely poor in quality and contained so many gas-forming bacteria that the control cheese (9A) was very gassy, resembling a sponge in appearance (Fig. 3). This cheese, lot 9A, had a bitter unclean flavor at both 7 and 12 weeks of age and at both scorings graded 4.6 for body and texture (very objectionable) and 5.0 for flavor (very objectionable). Surprisingly, cheese made from the same milk heated for 20 minutes at 145° F had a desirable body and texture (grade 1.6) and flavor (grade 2.3) at 12 weeks both in the case of lot 9B made with 0.05 per cent starter and lot 9C made with 0.10 per cent starter. Lots 9B and 9C were fully

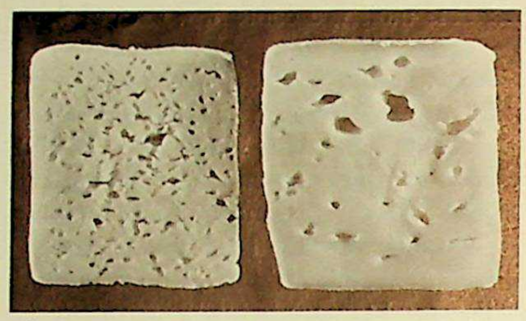

FIG. 3.—CONTROL OF GAS IN LIMBURGER CHEESE BY PASTEURIZATION.

Cheese at left with large numbers of gas holes made from raw milk (Lot 9A); cheese at right made from the same milk pasteurized for 20 minutes at 145° F (Lot 9B).

as good as any of the cheeses in series 3 to 8 made from milk which was not as gassy as that used in series 9. This indicates that limburger cheese made from pasteurized milk is much more uniform in quality than that made from raw milk, the harmful effects of bacteria of the coliform group on texture and flavor being prevented by pasteurization of the milk. It should not be interpreted from this that pasteurization is a panacea for the use of poor quality raw milk since undesirable types of bacteria may be present which survive pasteurization and produce flavor defects.

With raw milk of good quality as in the October studies, there was no advantage in pasteurization from the standpoint of improvement in quality. With raw milk of poor quality as in the July and August studies, there was a decided advantage in pasteurization. Pasteurization of milk on a year round basis would most certainly lead to a much more uniform product than it is now possible to make from raw milk of varying quality. Grades of October cheeses made from partly pasteurized and fully pasteurized milk were quite similar to those of July and August cheeses whereas the scores of the raw milk cheeses varied greatly.

## CHANGES IN HYDROGEN-ION CONCENTRATION

The role of pH values in relation to cheese quality has been shown by several workers. Price and Spicer (9) found that the chances of brick cheese developing acid defects were very slight if the pH was at least 5.1 at any time between the third and seventh days. Farrar (3) worked with Bel-Paese type cheese which has a moisture content similar to limburger and found that in the case of good cheese, pH values fell to about 4.9 in the first 24 hours and that there was relatively little change thereafter. Where acid development proceeded too slowly, the cheese was of poor quality.

Kelly and Marquardt (6) attribute lower pH values in normal limburger than in normal cheddar or brick cheese to a higher moisture content in limburger cheese with more lactose to be converted to lactic acid. They state that this lowering of the pH is desirable in making limburger cheese in that it keeps putrefying bacteria from growing.

Claussen (2) in Germany and Kelly and Marquardt (6) in New York studied pH changes during the ripening of limburger. Claussen found that normal ripening limburger showed after 24 hours a pH

TABLE 5.—EFFECT OF PASTEURIZATION AND OF STARTER ON pH VALUES OF LIMBURGER CHEESE MADE IN JULY AND AUGUST.

| Series and lot | Treatment of milk | | pH values | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Minutes at 145°F | Per cent starter | Milk at setting | Curd at dipping | Age in days | | | | | |
| | | | | | 1 | 7 | 14 | 28 | 49 | 70 |
| 3A | Raw | 0.00 | 6.58 | — | 5.01 | 5.14 | 5.54 | 5.86 | 6.66 | 6.90 |
| 3B | 30 | 0.00 | — | — | 5.35 | 5.09 | 5.31 | 5.73 | 6.70 | 6.95 |
| 3C | 30 | 0.10 | — | — | 4.95 | 4.97 | 5.24 | 5.56 | 5.68 | 6.16 |
| 3D | 30 | 0.20 | — | — | 4.91 | 4.98 | 5.22 | 5.46 | 5.68 | 5.89 |
| 4A | Raw | 0.00 | 6.64 | 6.32 | 5.04 | 4.55 | 5.44 | 5.76 | 6.73 | 6.92 |
| 4B | 30 | 0.00 | 6.63 | 6.59 | 5.38 | 4.55 | 5.33 | 5.56 | 6.18 | 6.48 |
| 4C | 30 | 0.10 | 6.64 | 6.49 | 4.90 | 5.00 | 5.20 | 5.59 | 5.81 | 6.18 |
| 4D | 30 | 0.20 | 6.64 | 6.50 | 4.90 | 5.71 | 5.10 | 5.51 | 5.74 | 6.08 |
| 5A | Raw | 0.00 | 6.57 | 6.26 | 4.96 | 5.10 | 5.47 | 5.81 | 6.61 | 6.90 |
| 5B | Raw | 0.05 | — | 6.26 | 4.94 | 5.07 | 5.70 | 5.86 | 6.30 | 6.73 |
| 5C | Raw | 0.10 | — | 6.23 | 4.96 | 5.07 | 5.49 | 5.86 | 6.34 | 6.69 |
| 5D | Raw | 0.20 | — | 6.23 | 4.96 | 5.15 | 5.47 | 5.81 | 6.20 | 6.62 |
| 6A | Raw | 0.00 | 6.59 | 6.66 | 4.72 | 5.23 | 5.40 | 5.95 | 6.38 | 6.73 |
| 6B | 0 | 0.00 | — | 6.48 | 4.85 | 5.30 | 5.48 | 5.87 | 6.42 | 7.14 |
| 6C | 15 | 0.00 | — | 6.57 | 4.95 | 5.23 | 5.33 | 5.75 | 6.42 | 7.17 |
| 6D | 30 | 0.00 | — | 6.57 | 5.05 | 5.23 | 5.24 | 5.72 | 6.66 | 7.28 |
| 7A | Raw | 0.00 | 6.61 | — | 4.88 | 5.11 | 5.33 | 5.89 | 6.56 | 6.53 |
| 7B | 0 | 0.05 | — | — | 5.12 | 5.13 | 5.33 | 5.71 | 6.27 | 6.66 |
| 7C | 0 | 0.10 | — | — | 5.05 | 5.13 | 5.23 | 5.71 | 6.27 | 6.70 |
| 7D | 0 | 0.20 | 6.58 | — | 5.05 | 5.13 | 5.18 | 5.64 | 5.99 | 6.63 |
| 8A | Raw | 0.00 | 6.58 | 6.47 | 4.93 | 5.05 | 5.30 | 5.76 | 6.35 | 6.98 |
| 8B | 10 | 0.05 | — | 6.54 | 5.10 | 5.01 | 5.20 | 5.59 | 6.04 | 6.51 |
| 8C | 10 | 0.10 | — | 6.51 | 5.09 | 5.18 | 5.30 | 5.63 | 6.35 | 6.60 |
| 8D | 10 | 0.20 | 6.62 | 6.44 | 5.06 | 5.05 | 5.24 | 5.63 | 6.04 | 6.63 |
| 9A | Raw | 0.00 | 6.64 | 6.57 | 5.02 | 5.13 | 5.42 | 5.93 | 6.65 | 6.55 |
| 9B | 20 | 0.05 | — | 6.54 | 5.12 | 5.13 | 5.32 | 5.62 | 6.37 | 6.41 |
| 9C | 20 | 0.10 | — | 6.54 | 4.95 | 5.13 | 5.20 | 5.40 | 5.98 | 6.63 |
| 9D | 20 | 0.20 | — | 6.54 | 4.98 | 5.06 | 5.20 | 5.54 | 6.25 | 6.40 |

below 5.0, on the average about 4.7. In general, the pH values sank to a minimum within one week after manufacture and then gradually began to rise. Kelly and Marquardt (6) studied pH changes in four different portions (surface, first $^5/_{16}$ inch, second $^5/_{16}$ inch, and center) and showed that while the pH of the surface slime rose to approximately 7.0 in about 1 week, the pH of the interior did not rise appreciably for several weeks and hardly reached the neutral point at any time during ripening, being around pH 6.9 when ready for market.

In the present study, pH values of the milk at setting ranged from pH 6.65 to 6.57 and of the curd at dipping from pH 6.66 to 6.23 (Tables 5 and 6). The lowest pH values in the case of the latter were obtained when samples could not be examined immediately. Otherwise, pH values were usually about 6.55, indicating that due to high buffer capacity, practically no change in pH took place between setting and dipping.

Changes in hydrogen-ion concentration in the cheese were determined 24 hours after dipping and at varying intervals up to 70 days of age. The pH values represent values of cross section slices which included the smear and rind. Determinations made after 4 days indicate the average rate of ripening of the cheese rather than the extent of acid development. Kelly and Marquardt (6) have shown that the pH readings of the surface and of the portion next to the surface

TABLE 6.—EFFECT OF PASTEURIZATION AND OF STARTER ON pH VALUES OF LIMBURGER CHEESE MADE IN OCTOBER.

| SERIES AND LOT | TREATMENT OF MILK | | pH VALUES | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Age in days | | | | | | |
| | Minutes at 145°F | Per cent starter | Milk at setting | Curd at dipping | 1 | 2 | 3 | 21 | 35 | 49 | 70 |
| 10A | Raw | 0.00 | 6.65 | 6.52 | 5.08 | — | 5.05 | 5.25 | 5.75 | 5.88 | 6.52 |
| 10B | 10 | 0.00 | — | 6.65 | 5.89 | — | 5.60 | 5.10 | 5.50 | 5.86 | 6.75 |
| 10C | 10 | 0.10 | — | 6.65 | 4.97 | — | 4.96 | 5.30 | 5.63 | 5.95 | 7.02 |
| 10D | 10 | 0.20 | — | 6.59 | 5.00 | — | 4.96 | 5.22 | 5.72 | 6.03 | 7.00 |
| 11A | Raw | 0.00 | — | 6.60 | 5.10 | 5.05 | — | 5.20 | 5.63 | 6.00 | 6.85 |
| 11B | 20 | 0.00 | — | 6.60 | 5.93 | 5.60 | — | 5.15 | 5.50 | 5.85 | 6.78 |
| 11C | 20 | 0.10 | — | 6.60 | 4.98 | 4.92 | — | 5.25 | 5.51 | 5.72 | 6.53 |
| 11D | 20 | 0.20 | — | 6.60 | 4.98 | 4.95 | — | 5.25 | 5.63 | 5.75 | 6.58 |
| 12A | Raw | 0.00 | — | 6.55 | 5.10 | — | — | 5.29 | 5.63 | 5.85 | 6.55 |
| 12B | 30 | 0.00 | — | 6.60 | 5.80 | — | — | 5.37 | 5.63 | 5.99 | 6.70 |
| 12C | 30 | 0.10 | — | 6.54 | 5.00 | — | — | 5.29 | 5.55 | 5.68 | 6.22 |
| 12D | 30 | 0.20 | — | 6.55 | 4.94 | — | — | 5.19 | 5.47 | 5.90 | 6.29 |

start to increase at about 4 days, whereas the pH of the remainder of the cheese changes but little for several weeks.

A determination of pH values of portions taken from the interior might well have been included in order to establish more definitely changes in hydrogen-ion concentration. Such data would probably have greater value in predicting normal or abnormal changes than data obtained from cross section samples. The pH values were determined at 1, 7, 14, 28, 49, and 70 days in the case of the July-August cheeses and at 1, 2, 3, 21, 35, 49, and 70 days in the case of the October cheeses. It was not convenient to obtain pH values at more frequent intervals during the first 14 days due to absence from the factory. There is need for further work along these lines to establish critical pH values for limburger such as has been done for other types of cheese.

### THE pH VALUES OF CHEESE MADE FROM RAW MILK

The rise in hydrogen-ion concentration was most rapid during the 24 hours following dipping. At this time pH values of control cheeses made from raw milk without starter ranged from 4.72 to 5.04 in July and August and from 5.08 to 5.10 in October. At 7 days, pH values in the case of the July-August cheeses were slightly higher than at 24 hours and ranged from pH 5.05 to 5.23 (one exception, 4A, where pH values dropped from 5.04 to 4.55). From this time on, pH values rose steadily, ranging from 6.53 to 6.98 at 70 days of age. In the case of the October cheeses, pH values of lots 11A and 10A at 2 and 3 days of age, respectively, were 5.05, approximately the same as the pH values at 1 day.

The average pH values of six raw milk cheeses made in July and August (omitting 4A) and three made in October are plotted (Fig. 4). The graph shows clearly that acid development during the first 24 hours was more rapid in the July and August cheeses than in the October cheeses. It should be pointed out, however, that the lower part of the curves, especially for the October cheeses, is only approximate due to limited data, as previously discussed.

Higher pH values for July and August cheeses than for October cheeses after about 5 days of age are to be attributed largely to higher cellar temperatures during the first 10 to 14 days, 70° F, compared to 60° F which hastened ripening. At 70 days of age, when the cheeses were fully ripened, average pH values of the July and August and

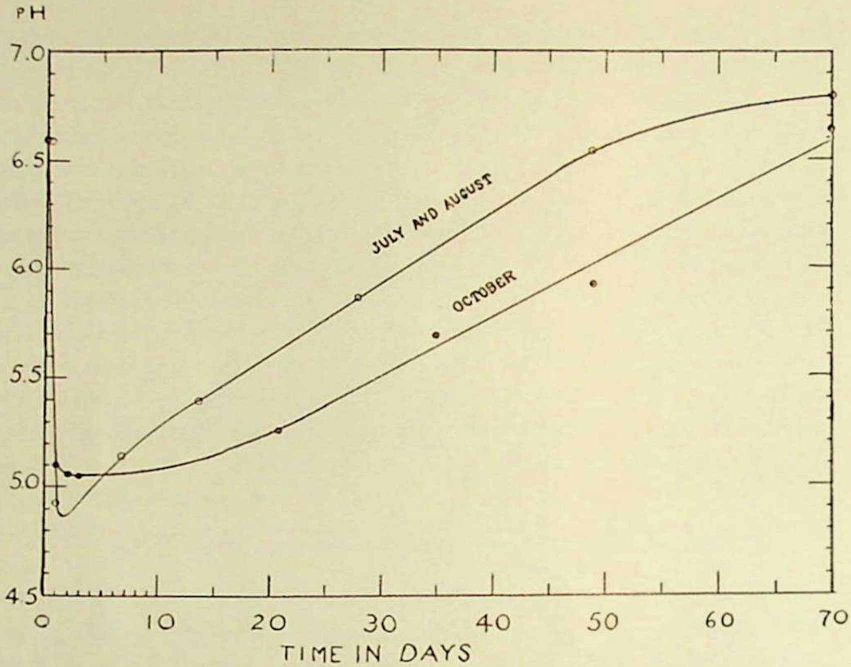


FIG. 4.—CHANGES IN pH VALUES OF SIX RAW MILK LIMBURGER CHEESES MADE IN JULY AND AUGUST AND OF THREE MADE IN OCTOBER.

of the October cheeses were about the same, being pH 6.79 and 6.64, respectively.

### EFFECT OF PASTEURIZATION ON pH VALUES

As shown previously, pasteurization retarded but did not stop acid development. This is brought out clearly by pH values in series 6 where no starter was used. At 24 hours, cheese made from raw milk (lot 6A), from milk heated at 145° F without holding (lot 6B), from milk held for 15 minutes (lot 6C), and from milk held for 30 minutes (lot 6D) had pH values of 4.72, 4.85, 4.95, and 5.05, respectively. Cheeses made from milk pasteurized for 30 minutes and without starter (lots 3B, 4B, and 6D) had pH values at 24 hours about 0.3 pH higher than the control cheeses made from raw milk. At 7 days, pH values were practically the same for both raw and pasteurized milk cheeses.

In October, cheeses made from milk heated for 10, 20, and 30 minutes at 145° F and without starter had values at 24 hours of pH 5.89, 5.93, and 5.80, respectively, compared to pH 5.08, 5.10, and 5.10 for

raw milk cheeses which indicates that acid development took place more slowly in the pasteurized milk cheeses than in the raw milk cheeses. However, acid development continued and at 21 days the pH values in the case of the pasteurized milk cheeses, 5.10, 5.15, and 5.37, were practically the same as those of the raw milk cheeses, pH 5.25, 5.20, and 5.29, respectively.

The desirability of this first drop in pH has been shown by Claussen (2) and by Kelly and Marquardt (6). Claussen found that defective cheese made without starter from pasteurized milk had a pH of around 6.0. Kelly and Marquardt (6) made two lots of limburger from milk pasteurized at 143° F for 30 minutes. The pH did not drop below 6.0, being followed by a steady rise in pH. When examined at a later date, the cheese had developed a strong putrid odor. Another lot was made to which 2 ml. of starter per gallon was added. The pH dropped to 5.0 by the third day and a typical limburger developed. This indicates that acid development is necessary to control putrefying bacteria.

Desirable cheeses were sometimes made in the present studies without the addition of starter to pasteurized milk and two lots, 3B and 12B, were decidedly superior to cheeses made with starter. In other instances, such as in series 10 and 11, a small amount of starter improved the quality of the cheese made from pasteurized milk. These results do not necessarily conflict with those obtained by Claussen (2) and by Kelly and Marquardt (6), but the differences may be attributed to differences in milk supplies. The numbers and types of organisms which survive pasteurization and their activity determine whether acid development will be sufficient to control putrefactive types. This viewpoint is supported by the work of Zeiler and Berwig (12) who in one trial made excellent cheese without starter from milk pasteurized by the holding method. However, they found that an amount of 0.10 to 0.20 per cent starter was usually necessary to bring about a normal ripening relation.

## EFFECT OF STARTER ON pH VALUES

The addition of 0.05 to 0.20 per cent starter to partly or completely pasteurized milk hastened acid development to such a degree that in 24 hours, pH values were usually about 5.0, being appreciably lower than where no starter was used. These pH values at 24 hours were within 0.2 pH of the values for the cheeses made from raw milk without starter (Tables 5 and 6 and Fig. 5).

During ripening, pH values of cheeses made from milk containing

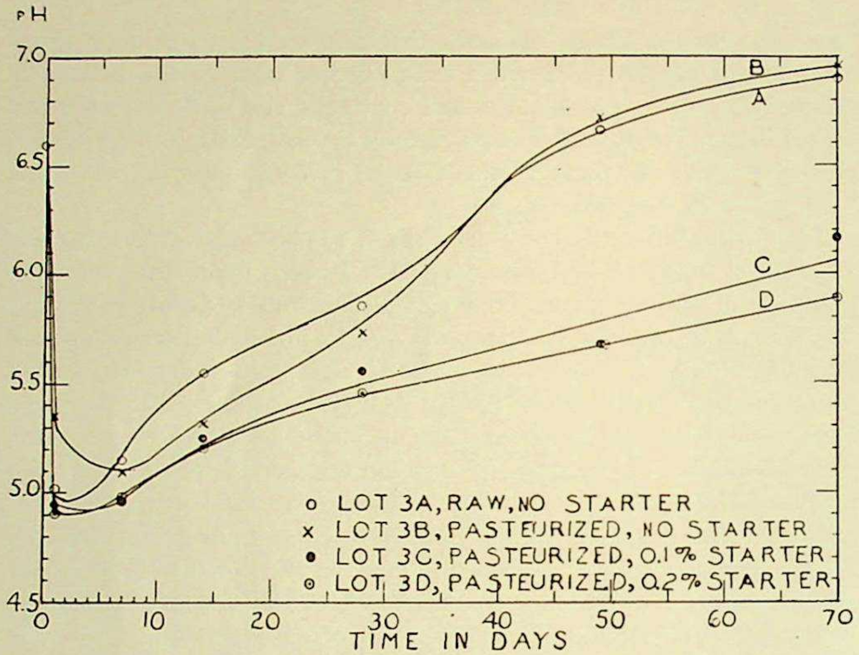


FIG. 5.—EFFECT OF PASTEURIZATION AND OF STARTER ON pH VALUES OF LIMBURGER CHEESES MADE IN SERIES 3.

starter tended to increase more slowly than did the pH values of raw and pasteurized milk cheeses made without starter. In series 3 (Fig. 5), pH values at 70 days were 6.90 and 6.95 for the cheeses made without starter as compared to pH 6.16 and 5.89 for the cheeses made with starter which were firm and dry with body and texture resembling brick cheese.

The importance of determining the pH values of different portions of the cheese was not fully appreciated until late in the study when data were obtained on lots in series 10 to 12 at a time when the cheeses were ready for consumption (Table 7). Average pH values of lots 10A to 11B with moisture contents ranging from 48.2 to 51.5 per cent were higher than those of lots 11C to 12D with moisture contents ranging from 42.7 to 46.5 per cent. Average pH values for the first $^5/_{16}$ inch, the second $^5/_{16}$ inch, and the center were in the case of the high moisture group 7.03, 6.57, and 6.05, respectively, and in the case of the low to medium moisture group, 6.81, 6.06, and 5.60 respectively. These results are to be expected since cheese high in moisture ripens more rapidly than cheese low in moisture.

TABLE 7.—HYDROGEN-ION CONCENTRATION OF OUTER, NEXT TO OUTER, AND CENTER PORTIONS OF LIMBURGER CHEESE MADE IN OCTOBER.

| Lot | Moisture content, per cent | pH values at 70 days | | |
|---|---|---|---|---|
| | | First $\frac{5}{16}$ inch (including surface) | Second $\frac{5}{16}$ inch | Center |
| I. Cheese High in Moisture | | | | |
| 10A | 48.7 | 6.80 | 6.45 | 6.00 |
| 10B | 51.5 | 7.02 | 6.59 | 6.26 |
| 10C | 48.9 | 7.22 | 6.65 | 5.89 |
| 10D | 48.2 | 7.26 | 6.85 | 6.30 |
| 11A | 49.2 | 6.95 | 6.50 | 6.02 |
| 11B | 49.7 | 6.94 | 6.37 | 5.85 |
| Average pH | | 7.03 | 6.57 | 6.05 |
| II. Cheese Low to Medium in Moisture | | | | |
| 11C | 46.2 | 6.75 | 6.10 | 5.68 |
| 11D | 45.7 | 6.90 | 6.20 | 5.68 |
| 12A | 46.3 | 6.85 | 6.10 | 5.59 |
| 12B | 46.5 | 6.90 | 6.30 | 5.88 |
| 12C | 44.1 | 6.75 | 5.95 | 5.55 |
| 12D | 42.7 | 6.70 | 5.70 | 5.25 |
| Average pH | | 6.81 | 6.06 | 5.60 |

In interpreting changes in hydrogen-ion concentration due to starter, the moisture content of the cheese should be considered. Lots 10D, 11D, and 12D made in October from milk containing 0.20 per cent starter had different moisture contents, 48.2, 45.7, and 42.7 per cent, respectively, and appreciably different pH values at 70 days, pH 7.00, 6.58, and 6.29, respectively (Table 6). Similar differences are shown in the pH values of the three layers which in the case of lots 10D, 11D, and 12D were pH 7.26, 6.90, and 6.70, respectively, for the first $^5/_{16}$ inch; pH 6.85, 6.20, and 5.70 for the second $^5/_{16}$ inch; and pH 6.30, 5.68, and 5.25 for the center portion (Table 7).

## DISCUSSION

The results of the studies with limburger cheese are similar to those obtained by other workers with cheddar cheese in that pasteurized milk produced cheese more uniform in quality but milder in flavor than cheese made from raw milk.

As may be expected with all types of cheese, the greatest improvement in quality is obtained thru pasteurization when the raw milk is poorest in quality. However, the use of milk of poor quality, whether raw or pasteurized, is not desirable in cheese manufacture. The presence of gas in raw milk is even more objectionable in the manufacture of limburger than in the making of cheddar. Pasteurization of the milk is the best way of overcoming the effect of gas. Under these conditions, limburger cheese made from pasteurized milk keeps better under storage conditions than raw milk cheese which develops bitter, unclean flavors.

Where the holding method of pasteurization is employed, a holding period of 30 minutes at 145° F may be employed without appreciable injury to the quality of the cheese. Results obtained by other workers indicate that higher temperatures for shorter periods of time, such as 160° F for 15 seconds, may also be used.

July and August cheeses were firm and dry when scored. Starter cheese usually were lower in moisture than those made without starter and this may have placed the starter cheese at a disadvantage.

An extensive study would have been necessary to determine those manufacturing procedures and other conditions necessary to attain uniform moisture to an extent sufficient to place all lots of experimental cheese on an entirely comparable basis. This was not attempted since it was doubtful whether the information gained would justify the time required. Furthermore, individual factories can attain moisture control thru their own manufacturing experience with large amounts of milk.

Yields from pasteurized milk should equal or exceed yields from raw milk. In October, it was observed that more fat was lost in the whey from the raw milk cheeses than from the pasteurized milk cheeses.

Cheesemakers who make limburger from pasteurized milk by the method commonly used with raw milk may in some instances be able to make an excellent product without the use of starter, while in other instances, they may need to use 0.05 or 0.10 per cent of starter to get the proper acid development. The sensitivity of limburger to small amounts of starter has been amply demonstrated in these studies. The cheesemaker will do well to attempt first to make limburger from pasteurized milk without starter, aiming at a moisture content in the finished cheese of approximately 46 per cent. Proper control of the cook and preventing rapid cooling of the curd during draining will

aid in this connection. When starter is not added to pasteurized milk, the curd may need to be held in the vat from 1 to 2 hours longer before dipping than where starter is used. Also, cheese made without starter tend to be greasy, but this may be overcome to some extent by proper handling in the cellar.

The chief objection to the use of starter with limburger is the tendency to dry out the curd with the development of a body and texture more nearly resembling brick cheese than limburger. Under these conditions, there is also less of the typical limburger flavor developed than where the cheese is made without starter. If starter is used, it is highly important that the precautions ordinarily observed in carrying cheese starters be followed.

More experimental work needs to be done along these lines using different milk supplies and types of starters and with variations in manufacturing methods. Results obtained by others indicate that variations from the manufacturing procedure commonly used are desirable in making limburger from pasteurized milk.

## SUMMARY AND CONCLUSIONS

Forty lots of limburger cheese comprising 172 1-pound cheeses were made from raw milk and from milk which had been heated to 145° F for 0, 10, 15, 20, or 30 minute holding periods. The method of manufacture was that commonly used for raw milk. The results may be summarized as follows:

1. Either partial or complete pasteurization (145° F for 30 minutes) improved the quality of cheeses made from gassy and poor quality milk in July and August, whereas there was no improvement in the quality of cheeses made in October from milk of better quality.

2. Pasteurization at 145° F for 30 minutes gave as good results as shorter holding periods.

3. Cheeses made from pasteurized milk had a milder limburger flavor than cheeses made from raw milk, and this flavor was usually present to the greatest extent when a lactic starter was not added to the milk.

4. In the case of the cheeses made from the heated milk, the optimum amount of starter varied. In some instances, starter was not beneficial while in others the addition of 0.05 or 0.10 per cent of starter improved the grade of the cheese. Larger amounts of starter resulted in a cheese which developed a body, texture, and flavor more nearly resembling brick cheese than limburger. Conclusions with respect to

starter hold true only for the manufacturing method used in these studies. Special manufacturing methods which may be desirable for use with pasteurized milk were not tried.

5. Pasteurization of the milk retarded acid development in the cheeses as shown by pH values but not to an extent sufficient to result in defective cheese.

6. Pasteurization of milk for the manufacture of limburger cheese results in a product of uniformly good quality when the proper manufacturing method is followed.

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